Analysis of Error in a Very High Frequency Omni-directional Radio Range (VOR) Station in an international Airport in Nigeria

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ABSTRACT

This work investigates the degree of error in a Very High Frequency Omni directional Radio Range (VOR) transmitter at an International Airport in Nigeria. The investigation involved the acquisition of a twelve-month measurement error in transmitters I and II of the VHF, Omni directional Radio Range (VOR) system present at the airport and subsequent analysis using Graph-pad prism 5.01. VHF Omni directional Radio Range enables the pilot to take - off and land safely.

It was observed that the VOR ground check error curve had maximum errors of: ±0.64°,±0.62°,±0.615°,±0.62°,±0.61°,±0.59°,±0.63°,±0.62°,±0.62°,±0.63°,± 0.62° and ± 0.615° for the months of January, February, March, April, May, June, July, August, September, October, November, and December, respectively. Comparatively, the months of January and June recorded the highest maximum errors of:±0.64° with an error spread of 1.28° and the least VOR ground check error of ±0.59° with error spread of 1.2° respectively. Thus, the signal radiations from the VOR base station, suffered the highest and the least interference in months of January and June, respectively. These errors could be attributed to interferences from some unintentional or malfunctioning, non-aeronautical, transmit signals with those from the VOR station. However, the errors were within the ICAO (International Civil Aviation Organization) Recommendation of permissible ground check error of ± 2 °. These signified that, the signal radiation from the VOR base station, suffered the highest and the least interference in months of January and June, respectively.

(Keywords: VOR, NAVAIDS, base station signal, radiations, ground check error curves, maximum error, minimum error, spread geomagnetic, frequency, interference).

INTRODUCTION

Navigation of aircrafts in today's world depends on Navigation Aids, NAVAIDS (which are Electronic instruments or markers that provide necessary assistance to aircrafts during navigation (Martin, et al., 2016; Kumar, 2016)). The NAVAIDS utilized by aircrafts are: Distance Measuring Equipment (DME), Instrument Landing System (ILS), Non-directional Beacons (NDB), Tactic Air Navigation (TACAN), and Very High Frequency Omni-directional Radio Range Instrument (VOR) just to list a few. Most of them operate at Very High Frequency (VHF) band. An ideal NAVAID has the following properties: extremely high precision, 100% accessibility, very high integrity, warning the user and shutting down when faulty, (CNS, 2017).

Unfortunately, it has been reported that, the performances of ground-based (NAVAIDS) present in some major air ports of the world, could be affected by interferences on the signals they radiate (FAA, 2014, ICAO, 2000; Amalu, 2019). Some of these interferences could be caused by some non-aeronautical, unintentional emitters and malfunctioning transmitters from the following: FM broadcast, scientific research centers, radio frequency medical equipment, industries, and power-lines (ICAO 2006, TC AIM, 2018).

The VOR is one of such NAVAIDS that could be affected. Actually, it is an electronic, navigation aid in an airport, which provides a pilot with azimuth information for both low and high altitude routes and airport approaches, ((Martin et al, 2016: Kumar, 2016).

A little error in VOR and ILS could cause a great disaster: ranging from disability to loss of lives and property, just to list a few. In addition, considering the wave of plane crashes, particularly at the airports, the need for monitoring the precisions of the various air navigation systems at various airports, cannot be over-emphasized (Robert, et al., 2015; Amalu, et al., 2019). Little wonder, that, ICAO (International Civil Aviation Organization) mandated that all air Navigational Aids be regularly monitored for correct radiation by an independently operating monitoring system (ICAO, 2000). Therefore, in this paper an effort has been made to ascertain the error level in the VOR instrument in an International airport in Nigeria.

LITERATURE REVIEW

The Very High Omni-Directional Radio Range (VOR)

The VOR is a short range, accurate NAVAID, operating between a radius of 74km - 370km on a power system of 50W or 100W, (ICAO, 2000). It consists of ground station transmitter (that operates in the frequency band of: 108.0 - 117.95MHz) and an aircraft receiver system. Its radiation enables the pilot to determine the plane's bearing with respect to the geomagnetic north and the VOR station via the plane's receiver and to remain on course.

In the absence of ground visibility, the VOR beacons utilized in marking airways provide guidance to high altitude aircrafts during final approach. The bearing is ascertained by measuring the phase difference, θ, between a frequency modulated reference signal and the amplitude, modulated variable signal in the aircraft's receiver (Martin, et al., 2016).

Amplitude modulation is the process of modulation in which the amplitude of the carrier wave is varied proportionately to the strength of the modulating signal, while, Frequency modulation is that, which produces variation of the carrier frequency proportionately to the amplitude of the modulating signal, (Thomas; 2019)). Both signals are usually transmitted at 30Hz from the VOR base station: the reference phase is radiated Omni-directionally, such that, it has an equal phase, ϕ in all direction, while, the variable signal rotates clockwise about the station with variable angles, θ as expressed in Figure 1.

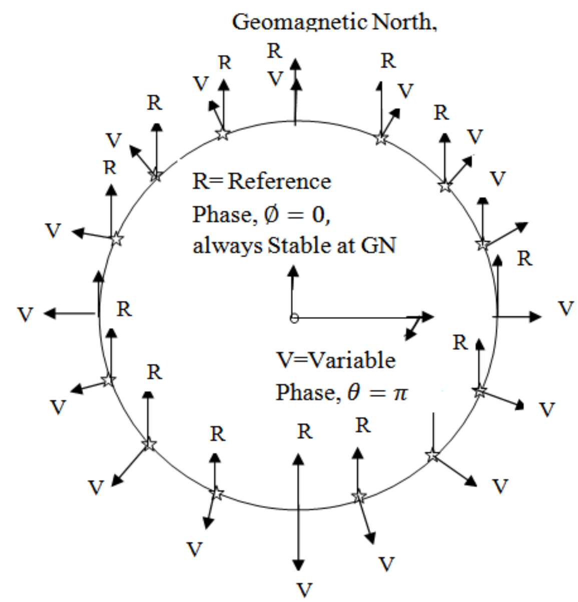


Figure 1: Transmission of Reference Phase Signal per unit time with the Variable Signals Sweeping through the Magnetic North.

The receiver in the plane intercepts the two signals and obtains the phase angle between them and reproduces the result in form of a radial from the station, which constantly points in an outward direction from the VOR system. It is important to note, that, in a perfect VOR system, for every degree clockwise movement of the variable signal around the VOR, it lags the reference voltage by one degree. In fact, it aids communication between the pilot and the ground VOR beacons (Charles, 2008; Thompson, et al., 2014; GN, 2017). In addition, the base transmitter does not only radiate voice, but also radiates tone identification signal. The voice signal allows transmission of weather and other miscellaneous information from the remote ground station (Martin, et al., 2016).

In terms of location, Airways are normally marked by a number of VOR ground beacons. VOR system that is located at an airport is called TERMINAL VOR (TVOR), while that located at any point along a flight path between airports is called ENROUTE VOR (O'Donnell, 2014, Thompson & Greenspan, 2014). The former with a transmitter power of 50W covers a range of 50km, while the latter with transmitter power of

200W covers a range of several hundred km (Nagabhashana and Sudha , 2010).

The VOR in the plane consists of a dual super-heterodyne system that is utilized by either the ILS localizer or VOR receiver, with a special control system that allows for the selection of the required frequency. Omni-directional selector enables the desired bearing to be selected and indicated on a 3-digit counter dial. A TO-FRO indication also shows whether the bearing selected is the course TO or FRO the VOR station. A TO-FRO switch reverses the TO-FRO indication which of course changes the magnetic bearing by 180^0. A Super-heterodyne system produces both sum and difference frequencies by the synchronization of two frequencies (Thomas, 2019).

The VOR also utilizes the deviation indicator of the ILS; the vertical needle is used for the VOR. The needle is centered when the aircraft is on the bearing indicated in the Magnetic bearing window of the Omni-Bearing selector. Indicator in an off-course aircraft shows, a 'Fly Right' or 'Fly Left' which signifies the direction the aircraft must be flown to reach the course of the Omni-Bearing Selector. The aircraft route must agree with the TO-FRO indication in order that the Deviation Indicator can be interpreted correctly (Nagabhashana and Sudha , 2010).

VOR Monitor

The VOR monitors ensure that, the radiated composite signals have correct amplitude and the 30Hz signals have the correct phase relationships. Therefore, in order to ensure the correct Azimuth, the amplitudes and frequencies of the radiated signals must remain on the specified values. An alarm threshold is set in an alarm circuit to provide for every specific parameter. In case of a fault in a dual installation, the monitor initiates a change-over to the standby transmitter. Monitors with remote controls could be controlled remotely from the tower.

The utilization of the VOR receivers installed in aircrafts, enable the Pilot to obtain the following information from DVOR or VOR radio navigation installation:

i. The azimuth indication of the aircraft's position relative to the ground beacon, i.e. the angle between magnetic North and the direction ground beacon to aircraft.

ii. The bearing which indicates whether the aircraft is flying to the left or right of the pre-selected course (position line) or whether it is exactly on it.

iii. The 'To and Fro' indication, which shows whether, either aircraft flying towards the (D) VOR beacon or away from it (TC AIM, 2018).

Accuracy of VOR System

It is important that, the accuracy of a VOR system be checked every 30 days as it is essential in ascertaining the following:

i. Track of VOR radials

ii. Any flight between omni-station and intersection.

iii. Approach and takeoff from airports (FAA, 2013).

Doppler VHF Omni-directional Radio Range (DVOR)

DVOR operates in similar form as the VOR, however, the major difference is that, in DVOR the reference signal is amplitude modulated, while, the variable is frequency modulated at 30Hz (GN, 2017).

METHODOLOGY

Data Collection

In this research, readings were obtained from the VOR Test facility (VOT) of the international airport in Nigeria. The method of ground check was adopted because, according to ICAO 8071, it could be utilized in the determination of course alignment error and in confirmation of the appropriate rotation of the VOR antenna without necessarily embarking on a flight inspection. The procedure involves.

i. Taking of monthly bearing error at transmitters: TXI and TXII of the Very

High Frequency Omni-directional Radio Range (VOR) system with reference to the Azimuth at bearing intervals of $20°$ and at a frequency of 113.7MHz.

ii. The analysis of the data, using Graph Pad prism 5.01 with subsequent determination of the maximum error, and the error spreads in the ground check error curves (i.e. a plot of the bearing error against the Azimuth on a two co-ordinate system).

SITE DESCRIPTION

Navigational Aids in the International Airport

The International airport has four (4) Navigational Aids that are necessary for safe landing and take- off of the airplanes: namely:

i. Very High Frequency Omni-directional Radio Range (VOR) which transmits at a frequency of 113.7MHz and is located at a 7km flight distance from the airport. Figure 2, presents the VOR Present at the international airport in Nigeria.

ii. Instrument Landing System (ILS) which comprises of Localizer (LOC): The LOC on the 18L Runway radiates at 108.1MHz while, that on 18R radiates at 110.3MHz.

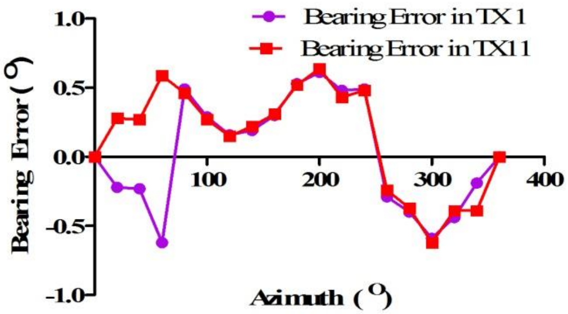
iii. Glide Slope (GS): The GS on the 18R Runway Transmits at 335MHz and 18L Runway Transmits at 334.7MHz.

iv. Distance Measuring Equipment (DME) which is co-located with the VOR.

The main concern in this research is the Very High Frequency Omni-Directional Radio Range (VOR) instrument.

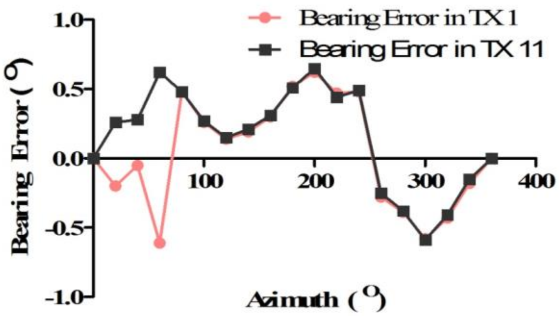
Figure 2: DVOR Ground Beacon at the Nigerian International Airport (N.A.M.A., 2019).

RESULTS



(a)

(b)



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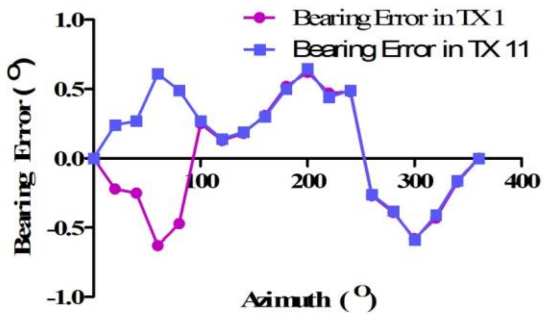

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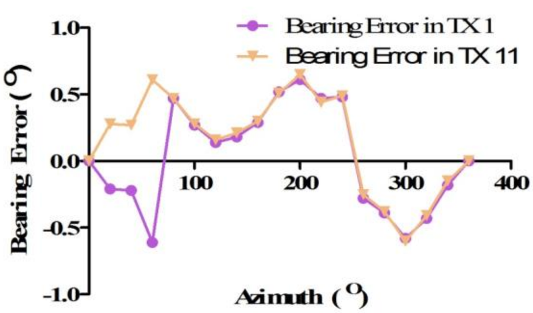

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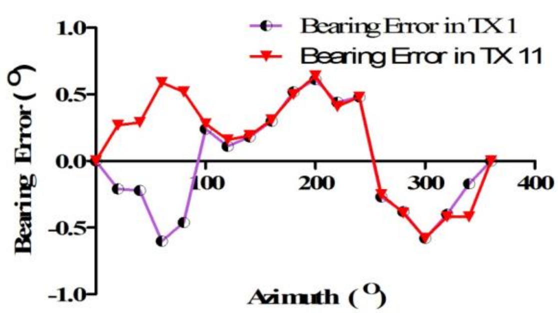

(f)

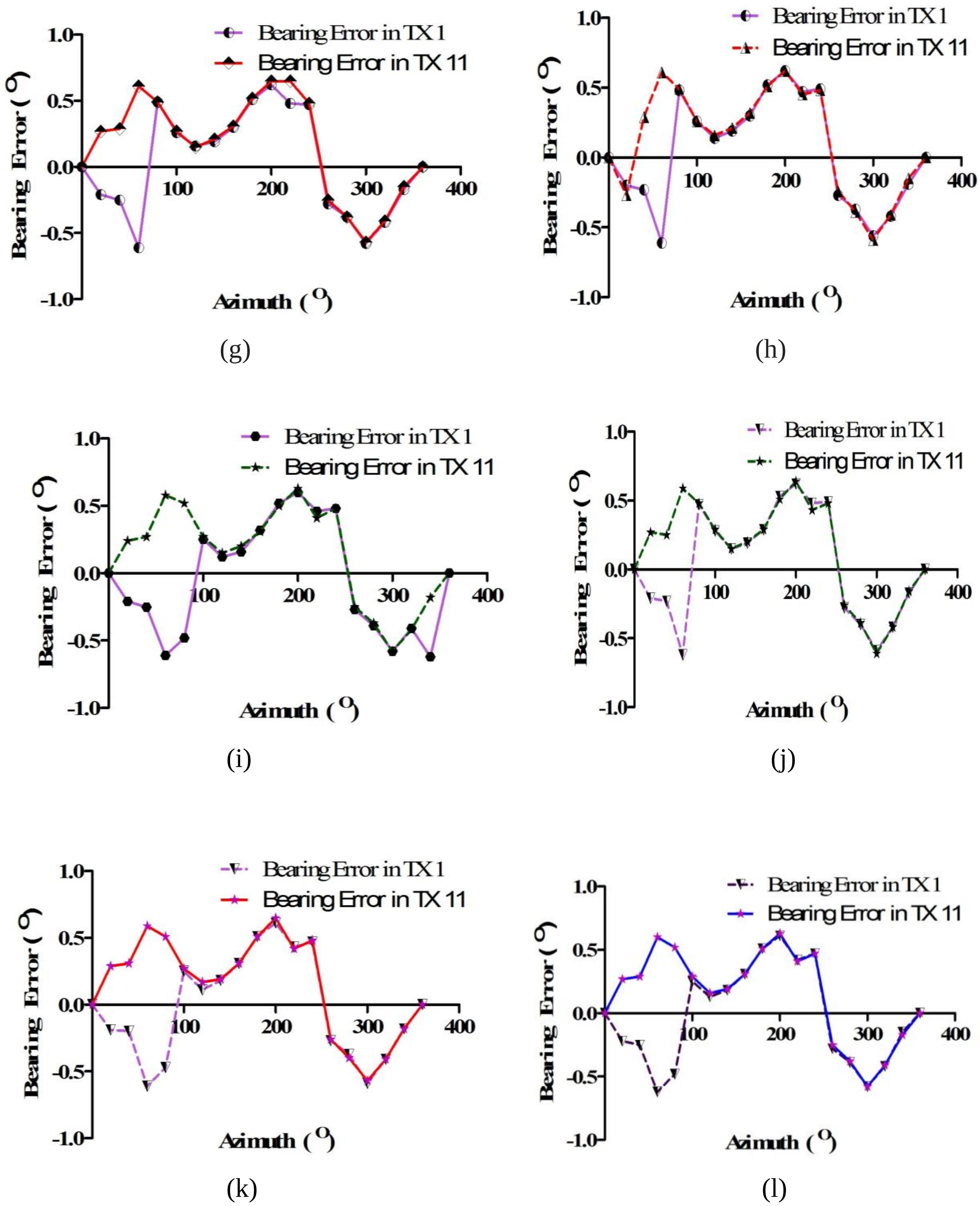

Figure 3: The Ground Error Check Curves for the Months of: (a) January, (b) February, (c) March, (d) April, (e) May, (f) June, (g) July, (h) August, (i) September, (j) October, (k) November and (l) December of a VOR Present in an International Airport in Nigeria.

DISCUSSION

It was observed that, the VOR ground check error curves in Figures: 3(a) to 3(l), had zero error at azimuths of $0°$ & $360°$ respectively. In addition, Figures: 3(a) to 3(l), do not only have negative course error between the azimuths of $260°$ - $340°$ but also have, positive course error between azimuths of $270°$ - $239°$. These, in accordance with ICAO 8071, signify that: the course was displaced anticlockwise from its actual position in the former, while, in the latter, the course was displaced clockwise from its true position.

Figure 3(a) had maximum error of $\pm 0.64°$ with an error spread of$1.28°$. It was further observed, that, errors of $+0.5°$ & $-0.29°$ were obtained at Azimuths of: $80°$ & $260°$, respectively. These, implied that, the actual courses radiated along the radials of $80°$ & $260°$ were: $79.5°$ & $260.29°$, respectively. Figure 3(b) had max error of $\pm 0.62°$ and an error spread of$1.25°$. At azimuths of$100°$ & $260°$, respective errors of$+0.24°$ & $-0.27°$ were obtained, thus, resulting in actual course radiations in the direction of $99.76°$ & $260.27°$, respectively.

The VOR ground check error curve in Figure 3(c) had maximum error of $\pm 0.615°$ with error spread of$1.24°$. Similarly, errors of $+0.48°$ & $-0.28°$ were obtained at Azimuths of: $80°$ & $260°$, respectively. These, denoted that, the actual courses radiated along the radials of $80°$ & $260°$ were $79.52°$ & $260.28°$, respectively.

Figure 3(d) had maximum error of $\pm 0.62°$ and error spread of$1.26°$. Further observation of figure 4(d) revealed that, errors of $+0.25°$ & $-0.29°$ were obtained at Azimuths of: $100°$ & $260°$, respectively. These, imply that, the actual courses radiated along the radials of $100°$ & $260°$ were $99.75°$ & $260.29°$, respectively.

Furthermore, in Figure 3(e) the VOR ground check error curve has maximum error of $\pm 0.61°$ and spread error of $1.23°$ with errors at Azimuths of $80°$ & $260°$ obtained as $+0.47°$ & $-0.28°$. These indicated that the actual courses at those azimuths were 79.53 $79.53°$ & $260.28°$, respectively. Furthermore, it was observed that, the ground error check curve in Figure 4(f) does not only have a maximum error of $\pm 0.59°$ but also, error spread of$1.2°$. Errors of$+0.24°$ & $-0.27°$ were obtained at azimuths of$100°$ & $260°$, respective. These values, signify actual course radiations of $99.76°$ & $260.27°$, respectively, instead of $100°$ & $260°$.

A maximum error of $\pm 0.63°$ and an error spread of $1.28°$ were deduced from Figure 4(g). It was observed that, at Azimuths of: $80°$ &$260°$, errors of: $+0.49°$ & $-0.28°$ were obtained, respectively, which resulted in actual course radiation of: $79.51°$ & $260.28°$, respectively along those Azimuths.

Figure 3(h) had maximum error of $\pm 0.62°$ and an error spread of $1.26°$. In addition, it also had errors of:$+0.48°$ & $-0.26°$ at Azimuths of: $80°$ & $260°$, respectively, which implied that: $79.52°$ & $260.26°$ were the actual course radiations along Azimuths: $80°$ & $260°$, respectively. However, there appears to be a periodic variation between Azimuths of $0°$ &$30°$. According to ICAO 8071 such periodic variation could be attributed to malfunctioning equipment or improper adjustment of equipment.

Similarly, the VOR ground check error curve in Figure 3(i) had maximum error and error spread of $\pm 0.62°$ & $1.25°$, respectively. At Azimuths of: $100°$ & $260°$, errors of: $+0.25°$ & $-0.27°$ were obtained, respectively, which indicated that, the actual courses radiated along the radials of $100°$ & $260°$ were $99.75°$ & $260.27°$, respectively.

Figure 3(j) had maximum error of $\pm 0.63°$ and error spread of$1.28°$ with errors at Azimuths of $80°$ & $260°$ obtained as $+0.47°$ & $-0.28°$. Thus, resulting in actual course radiations of: 79.53 $79.53°$ & $260.28°$, respectively along the Azimuths.

A maximum error of $\pm 0.60°$ and error spread of 1.2 were obtained from Figure 3(k). At Azimuths of: $80°$&$260°$, errors of: $+0.49°$ & $-0.28°$ were obtained respectively, which translated in actual course radiation of: $79.51°$ & $260.28°$, respectively along those Azimuths.

The ground error check curve in Figure 3(l) had maximum error of $\pm 0.625°$ and error spread of $1.26°$. In similar manner, errors of $+0.25°$ & $-0.28°$, were obtained at Azimuths of: $100°$ & $260°$, errors of: $+0.25°$ & $-0.27°$, which signified that, the actual courses radiated along the radials of $100°$ & $260°$ were $99.75°$ & $260.27°$, respectively. In accordance with ICAO 8071, the various degrees of error obtained could be attributed to slight interference from non-aeronautical transmitter.

Comparatively, the highest maximum error of $\pm 0.64°$ and a highest error spread of $1.28°$ were obtained from Figure 3(a), while, the least maximum error and least error spread of $\pm 0.59°$ and $1.2°$ were obtained from Figure 3(f). These signified that, the signal radiation from the VOR base station, suffered the highest and the least interference in months of January and June respectively. However, for angles of elevation between $0°$ & $40°$, all of the maximum errors recorded were within the ICAO's stipulated $\pm 2°$ ground station error contribution to the uncertainty in the bearing information resulting from horizontally polarized radiation from the centre of the VOR antennas.

CONCLUSION

The month of January recorded the highest maximum error of±0.64° with an error spread of1.28°, while, the month of June recorded the least VOR ground check error of ±0.59° with error spread of1.2°. Thus, the signal radiations from the VOR base station, suffered the highest and the least interferences in months of January and June, respectively. Interestingly, none of the maximum errors recorded exceeded the maximum acceptable error specified in ICAO 8071. Thus, the VOR instrument in the airport could be dimed to operate within the Standards and recommended Practices (SARPS).

RECOMMENDATION

It is therefore, recommended that, reflectors such as communication masts and tall buildings should not be sighted near NAVAIDS.

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